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14. ABSTRACT

Particulate migration is a concern in the transfer mechanics for photocathode assemblies in a superconducting RF environment. These issues have been successfully addressed during this project with the design of a dust free cathode transfer mechanism that can enhance the reliability of SRF electron guns. This design is compatible with ultra-high vacuum (UHV), ionizing radiation, cryogenic surfaces, and does not generate particles at the interface between the sample holder, the transfer arm, and the final holder positioning mechanism. Computer simulations of beam line diagnostics have been put into place to understand the optimization of SRF electron guns.

15. SUBJECT TERMS

Superconducting, Electron Gun, Beam Simulation, Cathode Transfer

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FINAL REPORT

Project Title:	CATHODE HOLDER AND TRANSFER MECHANISM DESIGN FOR WARM CATHODE IN SRF ELECTRON GUN
Principal Investigator:	Joseph J. Bisognano
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1.0 Project Objective

Both the Naval Postgraduate School (NPS) electron gun group and the Wisconsin electron gun group are developing superconducting RF guns for free electron laser applications. Since these programs are based on Niowave-fabricated, lower frequency quarter-wave structures, many commonalities exist that could benefit from collaboration. Under this grant and as a first step, the Wisconsin group developed a design for a dust free cathode transfer mechanism that would enhance reliability of these SRF electron guns. In addition, in preparation for collaboration with the NPS group, simulations of beam measurements were pursued that will enhance understanding of the mechanisms of electron bunch formation and emittance evolution. A revised statement of work including this added task was approved midway in the project period. Ultimately, this modeling will allow better optimization of the tuning parameters of these SRF quarter wave guns.

2.0 Work Completed

2.1 Cathode Transfer Holder and Mechanism

Particulate migration is a concern in the transfer mechanics for photocathode assemblies in a superconducting RF environment. This issue has been successfully addressed during this project with the design of a dust free cathode transfer mechanism that can enhance the reliability of SRF electron guns.

SRC has over a decade of experience transferring samples into preparation chambers for angle-resolved photoemission spectroscopy (ARPES) systems such as the Scienta R4000. These systems require high availability components that are compatible with ultra-high vacuum (UHV), operate at cryogenic temperatures, and are non-magnetic to prevent distortion of data acquisition by the electron spectrometer. These transfer mechanisms were suitable candidates for a design starting point of a cathode load lock. The major development required for transition from an electron spectrometer to a niobium super conducting cavity was eliminating or significantly reducing particle generation.

Historically samples have been transferred into the ARPES prep chambers using a disposable sample post attached to a reusable threaded slug, which was turned into a mating thread on a cryostat in the prep chamber via a magnetically coupled linear-rotary transfer arm. This is a very reliable, repeatable process, but the downside is the generation of particles at the thread interface. Redesign of the sample to cryostat interface was the critical element in a functional cathode transfer system. Once this

problem is solved, a preparation chamber and temperature regulated manipulator is relatively trivial.

The first item tested for particle generation was the linear-rotary transfer device. One of two methods is typically employed for this: an external stage with bellows, or a magnetically coupled internal mechanism. Both methods were developed and tested with cooperation from the component suppliers. SRC uses Transfer Engineering & Manufacturing's DBLRM series of linear rotary manipulators on its Science 200U and Scienta R4000 ARPES (Figure 1). SRC chose this particular manufacturer and series of manipulators for their magnetic coupling performance. Initial testing using a Lighthouse particle counter (Figure 2) showed that these units generate particles at the 0.3 micron size in the tens of thousands counts when sprayed with particle filtered nitrogen.

Figure 1. Transfer Engineering and Manufacturing DBLRM-36 magnetically coupled linear-rotary manipulator.

Figure 2. Lighthouse particle counter.

This is not acceptable for a low-particle application. Investigations determined that the root cause was the shedding of the dry lubricant from the rolling element bearings. Transfer Engineering & Manufacturing uses tungsten-disulfide (WS_2) coated bearings in the UHV series of manipulators. This "dry" lubrication is preferable to a "wet" lubricant in a UHV environment because its outgassing rate is lower and does not contain hydrocarbons. It was discovered that these bearings did generate particles up to 50,000 counts when allowed to spin freely while being sprayed with filtered nitrogen. A full ceramic bearing from a previous project was tested for particle generation. The test showed that after initial cleaning of accumulated particles from the environment, little to no more particles were being generated. Transfer Engineering sent samples of hybrid ceramic (metal races and retainer) and full ceramic (ceramic races and PEEK retainer) bearings for testing (Figure 3). The hybrid ceramic units generated particles, but the full ceramic bearings did not. It should be noted that these bearings still required cleaning with ethanol and filtered nitrogen to get them to a particle free state because they are not manufactured in a clean room environment.

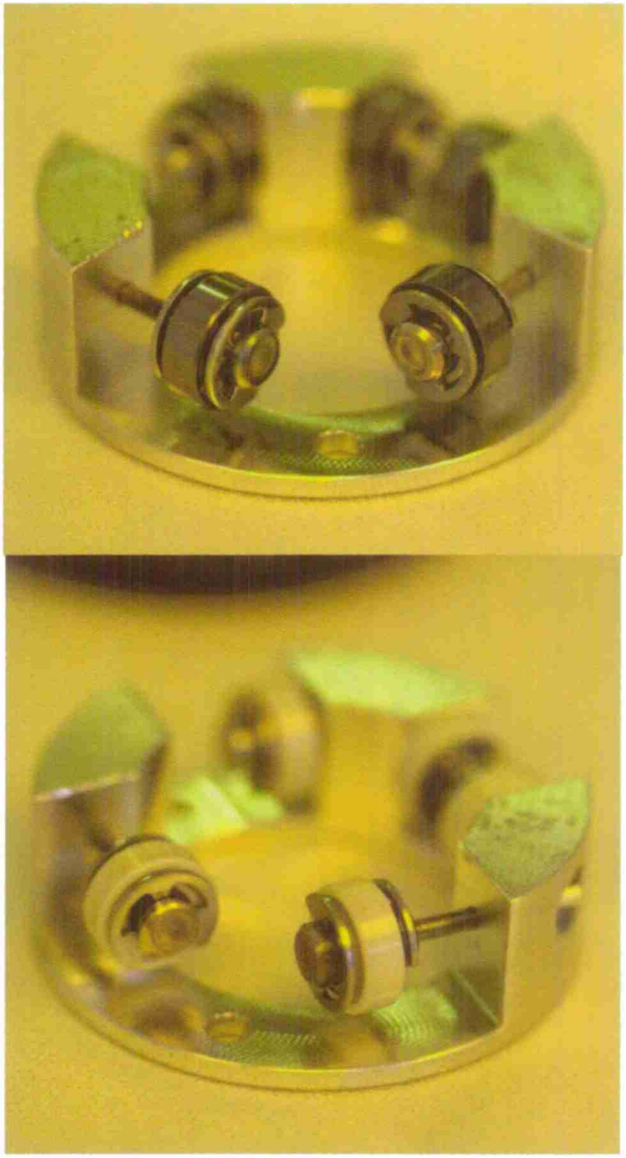

Figure 3. Hybrid ceramic bearings (top) and full ceramic bearings with PEEK retainer (bottom).

Concurrently with the bearing investigation, welded bellows were tested for their cleanliness. Two standard off-the-shelf bellows as well as a bellows cleaned by a third party were tested (Figure 4). The uncleaned bellows registered 0.3 micron particle counts on the order of 15,000 while spraying with filtered nitrogen. However, actuation of this bellows without spraying reduced the particle counts to room background in the range of 0 to 120. The third party "semi-conductor" clean bellows registered a maximum of 480 counts at 0.3 microns, eventually tapering off to 0 while being sprayed with filtered nitrogen.

Figure 4. Standard bellows (left), "semi-conductor" clean sample bellows (right).

Either actuation method appeared to be acceptable for this low-particle application. The magnetically coupled linear-rotary manipulator from Transfer Engineering was selected for its simplicity, compactness, and cost. The entire manipulator cost $7,000, about the price of an equivalent bellows without a supporting linear or rotary stage. The next step was designing a low particle transferrable cathode assembly. Other mechanisms use a conical centering layout, and a rotary locking mechanism. Based on the bearing tests, and previous sample transfer designs at SRC, it was determined that this was not the ideal approach for several reasons:

1. Sliding surfaces generate particles.
1. Due to machining tolerances, conical surfaces will not have optimal thermal contact.
3. Thermal expansion / contraction causes interference type fits to behave unpredictably, notably become cold welded and unable to be removed.

Addressing item one is to use rolling element bearings rather than a sliding surface. Additionally the stiffness and length of the transfer arm cause it and its payload to droop at the cavity end of the cathode stalk (Figure 5). Therefore a mechanism as listed above for self-centering would generate particles over a large distance even if the cathode had a relatively low mass. A rail system using full ceramic bearings was integrated into the bayonet device and cathode stalk (Figure 6). With or without the cathode payload, the transfer mechanism remains centered in the cathode stalk.

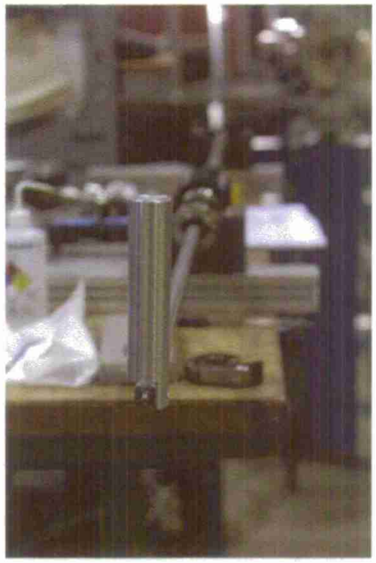

Figure 5. Manipulator droop test with simulated cathode load.

Figure 6. Cathode stalk centering rails.

For a better thermal contact, a vertical flat surface was used as the thermal interface (Figure 7). It is easier to manufacture a flat than a cone. A flat contact surface also addresses item three. The two flat thermal surfaces come into contact with each other normal to the direction of travel and are preloaded with a spring force, relying on friction to keep the cathode positioned. This should help keep the cathode from changing its position due to thermal expansion / contraction versus relying on a horizontal or slightly inclined supporting surface.

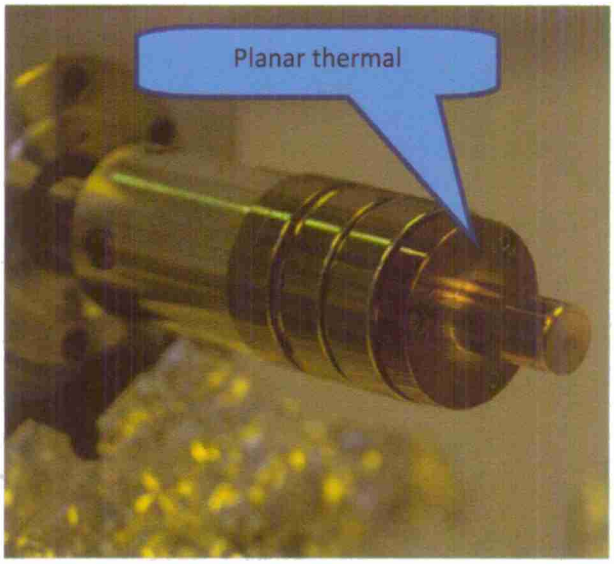

Figure 7. Cathode assembly attached to manipulator.

Figure 8. cathode assembly inserted into stalk mock-up, released from manipulator.

The spring preload is maintained with a cam actuated flexure (Figure 9). The flexure expands radially against the stalk tube, yet not touching the tube, but rather being pushed horizontally against the edge of a smaller bore as the preload spring expands. This locking / preload mechanism does not generate any external particles because there are no sliding interfaces. The internal cam and Vespel SP3 bushings are the only sliding parts, which are internal to the assembly, and any particles generated are kept inside the cathode assembly. This entire cathode assembly is removed when exchanging cathodes allowing decontamination between uses. Another concern addressed with this design was the possibility of dropping the payload in the cathode stalk. A design using a fork / four-pin style bayonet like on the SRC ARPES systems

has the possibility to disengage from the sample. In an ARPES prep chamber, dropping a sample is of little consequence. Dropping the cathode between its loaded and transfer position could potentially cause significant downtime. This design captures the bayonet and cam tool when the flexure is in its released position, eliminating the possibility of this occurrence.

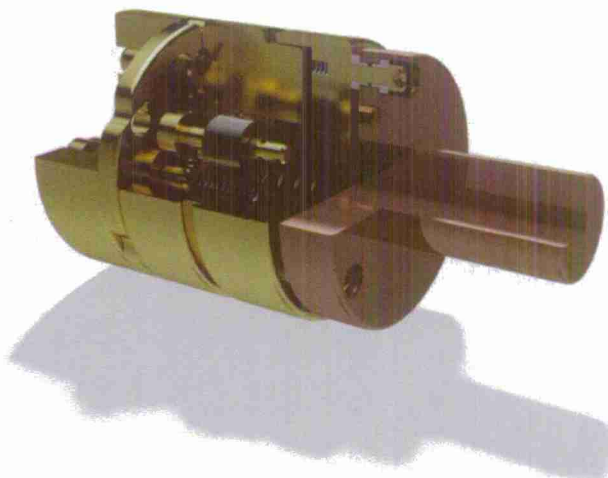

Figure 9. Cathode assembly flexure cam bearings (left), cathode assembly three quarter section (right).

Figure 10. Cathode stalk.

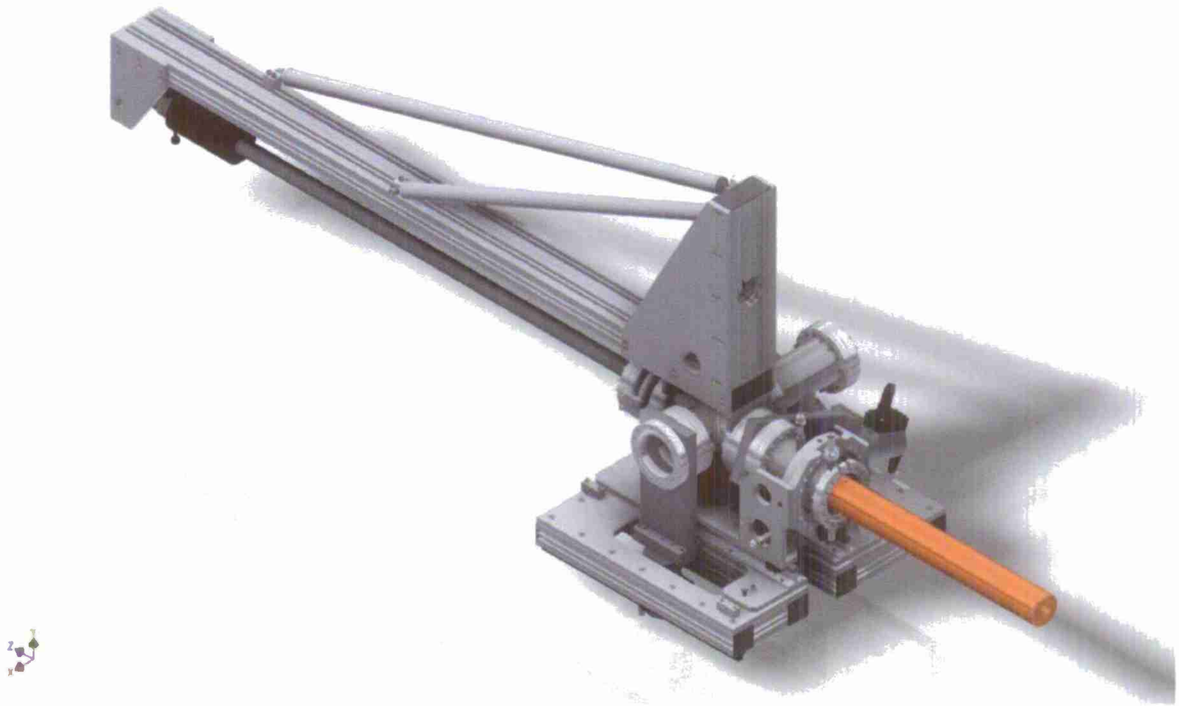

Figure 11. Cathode load lock & stalk module CAD model.

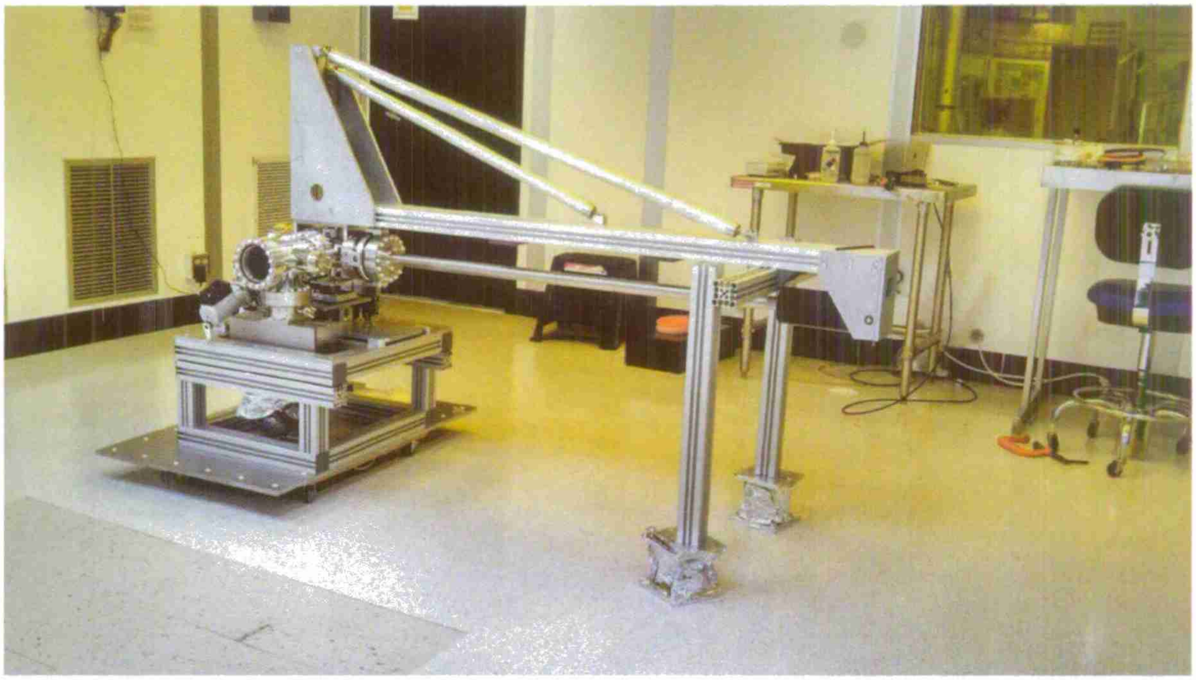

Figure 12. Cathode load lock & stalk module assembly in clean room.

2.2 Modeling of Electron Beam Diagnostics

The model the Wisconsin gun was extended to include the beam transport and diagnostics section. This modeling informed the finalization of the diagnostic beam line and puts in place tools necessary to interpret measurements, both for the Wisconsin gun and for use in the NPS quarter-wave guns. In the following, we describe in some detail the investigations.

Simulations have been performed to study transport of bunches with and without a 30-degree dipole magnet that bends into the energy diagnostic line. The use of a quadrupole doublet to focus the beam into a Faraday cup has been modeled to determine the required quadrupole field strength. In addition, bunch propagation downstream of slits has been studied by modeling the transport without space charge. Simulations have been performed for design operation, as well as the degradation that arises from dipole and quadupole errors in the solenoid and non-optimal solenoid strength. For example, Figure 13 shows the increase in emittance resulting from a horizontal dipole error in the solenoid, indicating that the integrated dipole error should be less than 90 G-cm to prevent an emittance increase exceeding 10%.

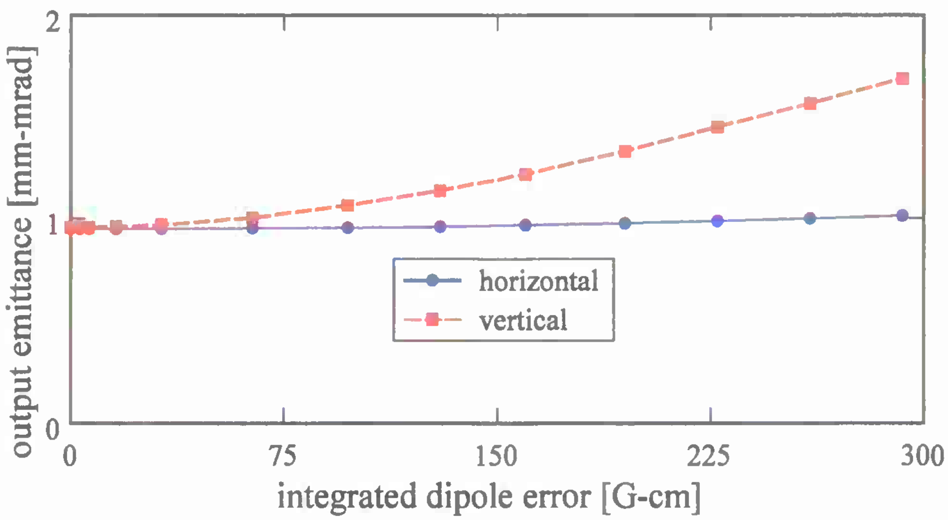

Figure 13. Projected horizontal and vertical normalized emittance vs. horizontal dipole error of the solenoid.

Simulations have also been performed to model performance if the design RF gradient of 41 MV/m is not achieved (or if an increased gradient is obtainable), including an optimization of solenoidal field and laser spot size for different values of the RF gradient. For example, Figure 14 shows the projected and slice emittances and slice

energy spread vs. RF gradient when the laser spot is the optimal size for the design gradient, for the case where the solenoid strength is optimized for each value of RF gradient.

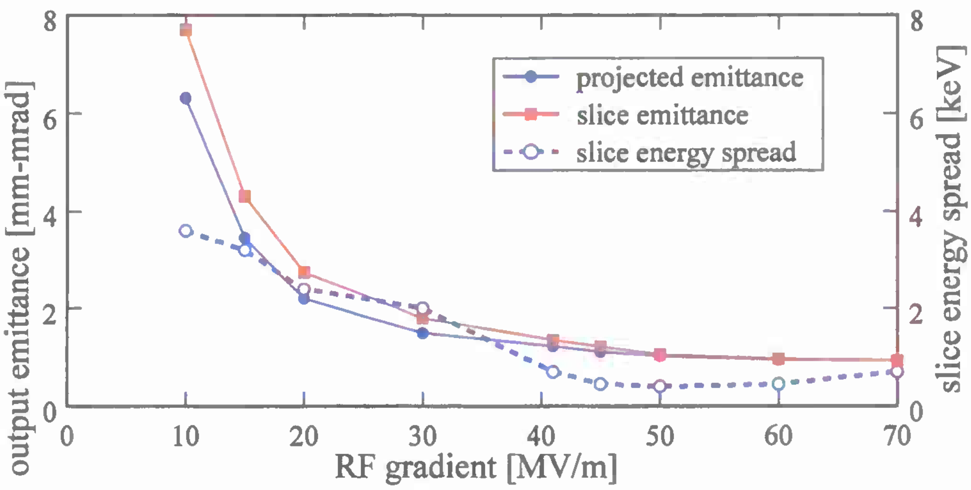

Figure 14. Projected emittance, slice emittance and slice energy spread (at the bunch center) w1vs. RF gradient.

Simulations with a 20-pC bunch have been performed to find the peak current (7 A), transverse emittance (0.3 mm-mrad) and slice energy spread (0.6 keV) that can be obtained. Simulations of lower initial emittance bunches, potentially obtainable with improved cathode materials, have explored the enhanced performance possible with improved cathode materials.

3.0 Conclusions

Particulate migration is a concern in the transfer mechanics for photocathode assemblies in a superconducting RF environment. This issue has been successfully addressed during this project with the design of a dust free cathode transfer mechanism that can enhance the reliability of SRF electron guns. The design is compatible with ultra-high vacuum (UHV), ionizing radiation, cryogenic surfaces, and does not generate particles at the interface between the sample holder, the transfer arm, and the final holder positioning mechanism. Any particles that may be generated elsewhere are trapped inside the mechanism, and are able to be removed with typical UHV and low particle cleaning methods such as ultrasonic chemical baths and high pressure ultra-pure water rinses. Basically, the transfer mechanism used encapsulates any generated dust particles inside it. External contact surfaces do not slide past each other, but rather make contact along surface normals, therefore not generating particles between it and the cavity.

The transfer mechanism utilized in the load lock securely attaches to the sample holder, easing repeatability of alignment without the use of conical centering devices that are prone to particle generation due to the sliding interface. It also minimizes the probability of the sample holder becoming trapped inside the assembly, therefore minimizing downtime to evaluate the system and/or vent the system to replace the cathode stalk.

In addition, computer simulation of the operation of beam line diagnostics has been performed that puts into place the tools necessary to understand the operation and optimization of quarter-wave superconducting RF electron guns. The general applicability of these simulations provides the foundation for future collaborations with electron gun efforts at the Naval Postgraduate School.